

# *Economics of LED manufacturing: Yesterday, Today and Tomorrow*

**DOE SSL Market Introduction Workshop**

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See disclosures in Appendix

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# Agenda

- Who we are
- The energy dilemma
- The Second & Third Cycles
- MOCVD
- Policy review
- What does it all mean?
- Beyond the myopic solutions
- OLEDs in lighting
- Summary



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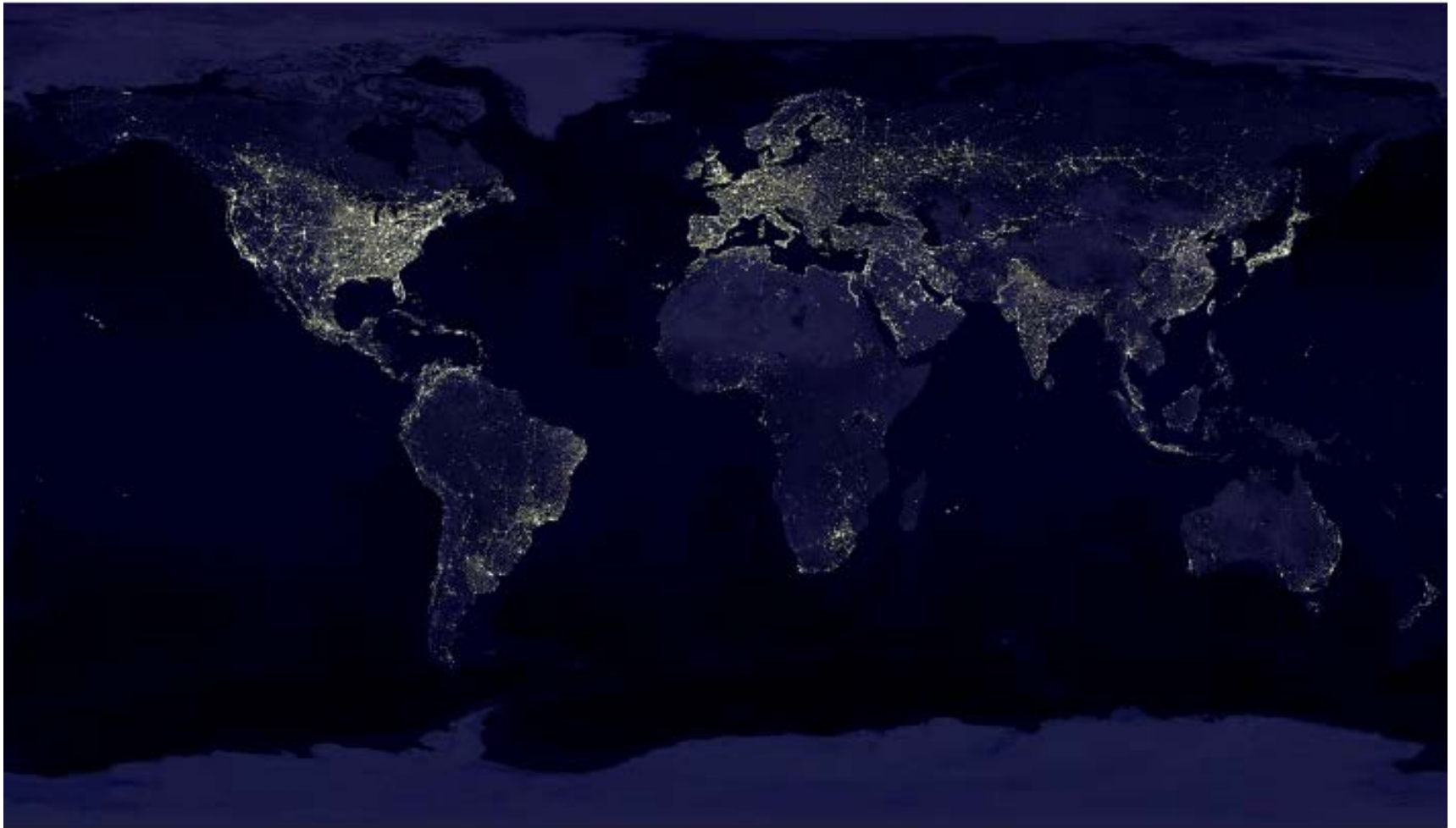
## DEEP INDUSTRY KNOWLEDGE ACROSS SECTORS



## EXPERTISE ACROSS MARKETS



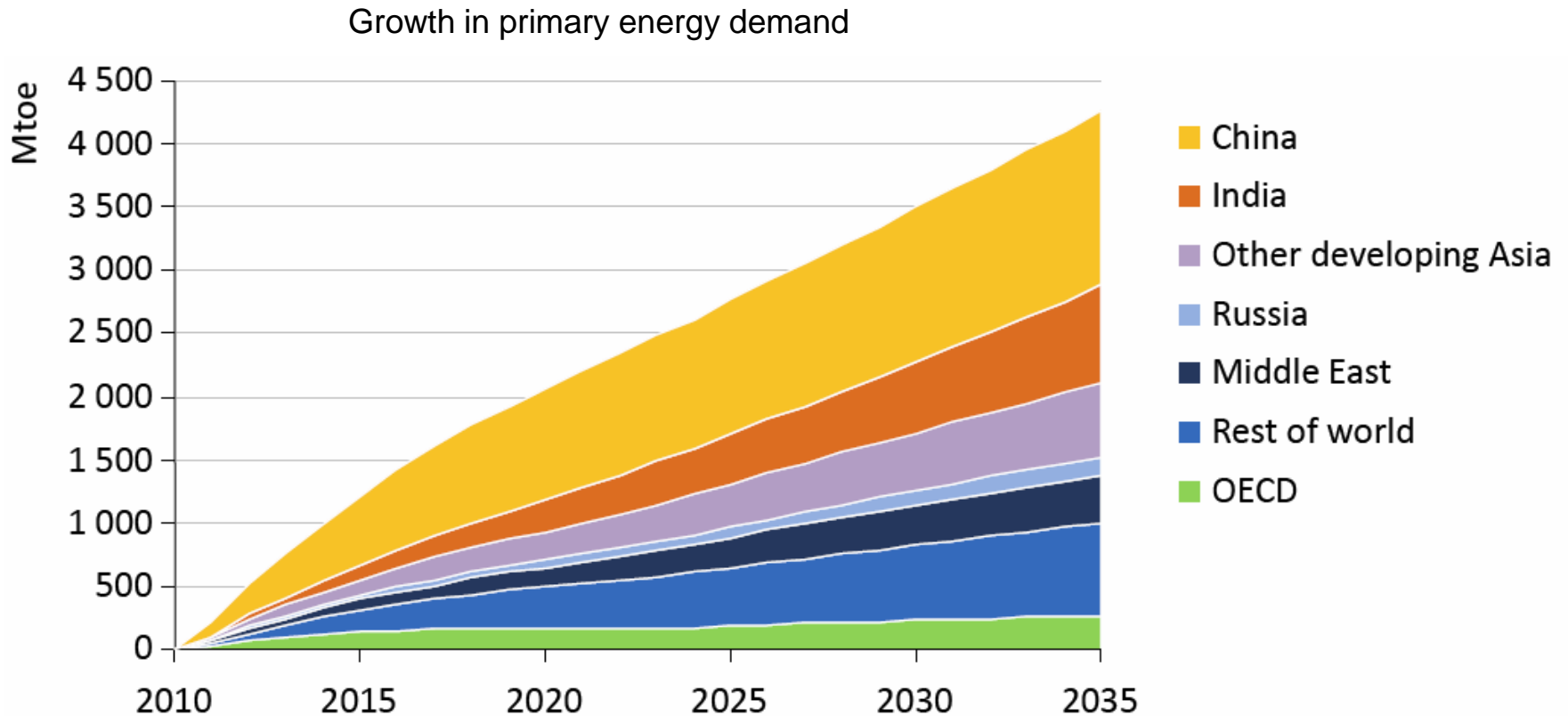
# The Energy Dilemma



Photograph: NASA

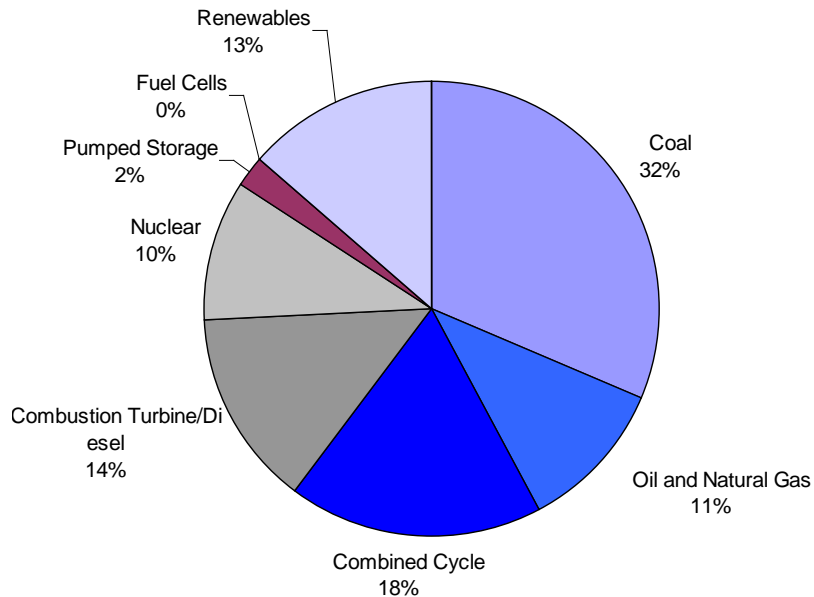
# Energy – Demand

- Global energy demand to increase by 33% from 2010 to 2035
  - China and India alone make up 50% of the growth

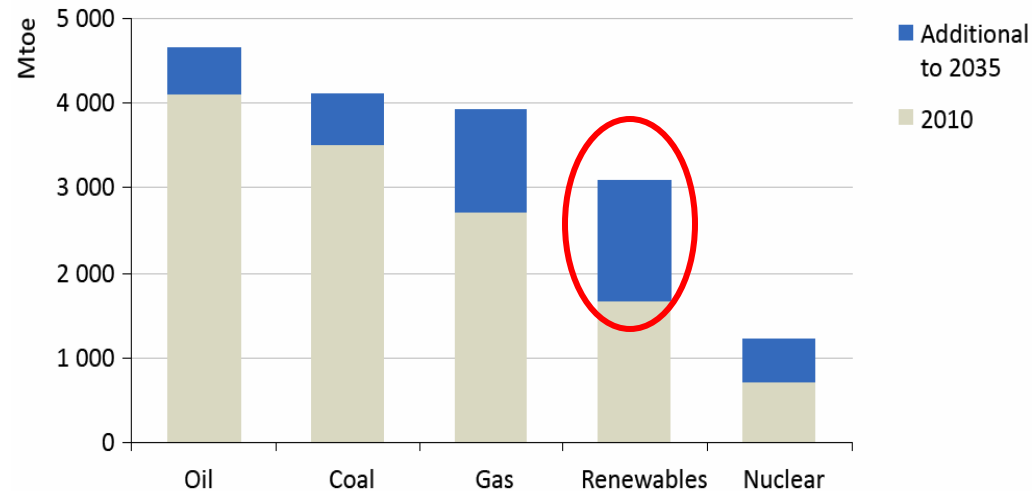


# Energy - Supply

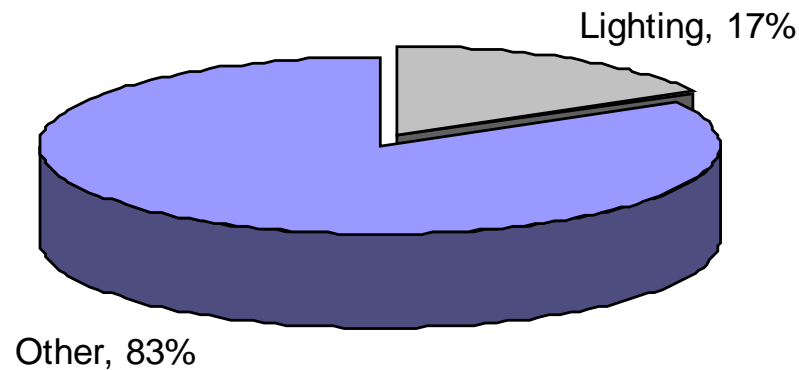
**US Electric Generation Capacity (2011)**



**Renewables to account for much of the incremental supply**



## Worldwide Electricity Consumption



2011: 18 Billion kWh total electricity consumption,  
3B kWh was for lighting

# The world needs to go on an energy diet





# The Second Cycle

## First ever bottom up MOCVD reactor supply model

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Sustainability -- Energy & Power Technologies

## The Second Cycle

*Worldwide LED supply/demand analysis and technology primer*

- Our base case supply/demand scenario highlights that LED manufacturing capacity is quickly heading for a significant shortage around 2010. We conclude that meeting the projected demand will require between 800 and 650 high-capacity MOCVD reactors worth \$650 million to \$1.4 billion. As such, we see the current cycle as a bullish indicator for both of the incumbent equipment suppliers.
- Our prediction of a capacity shortage is driven by a 20% CAGR forecast in total LED demand through 2012, resulting in projected revenue ranging from \$15.8 billion to \$24 billion. The largest drivers of this demand forecast are notebook and LCD TV backlighting, which we expect to go to 95-100% penetration and to 20%-50% penetration by 2012, respectively. We predict general lighting will represent the next wave of LED growth, at only 10%-18% of total LED revenues in 2012.
- Our analysis concludes yield losses at the reactor and packaging levels are well below optimal, suggesting further vertical integration between epi, chip, and package companies in an attempt to bring up yields, as well as a renewed focus on manufacturing techniques in an effort to drive down costs.
- We see the Chinese market as very large, yet almost impossible to quantify in terms of actual demand. China presents a critical sales channel for many non-Chinese LED suppliers as an outlet for the large quantities of "off spec" die from the poor yields mentioned above. This market is likely to be increasingly served by domestic Chinese manufacturers as they climb the learning curve in LED capacity and manufacturing processes, placing greater emphasis on distribution schemes and pressuring margins.
- New entrants such as Samsung and LG Electronics should bring greater scale and manufacturing expertise from traditional semiconductor markets. However, it is too soon to be certain how successful and what yields these companies will achieve, and what the implications are for the industry's supply/demand balance.

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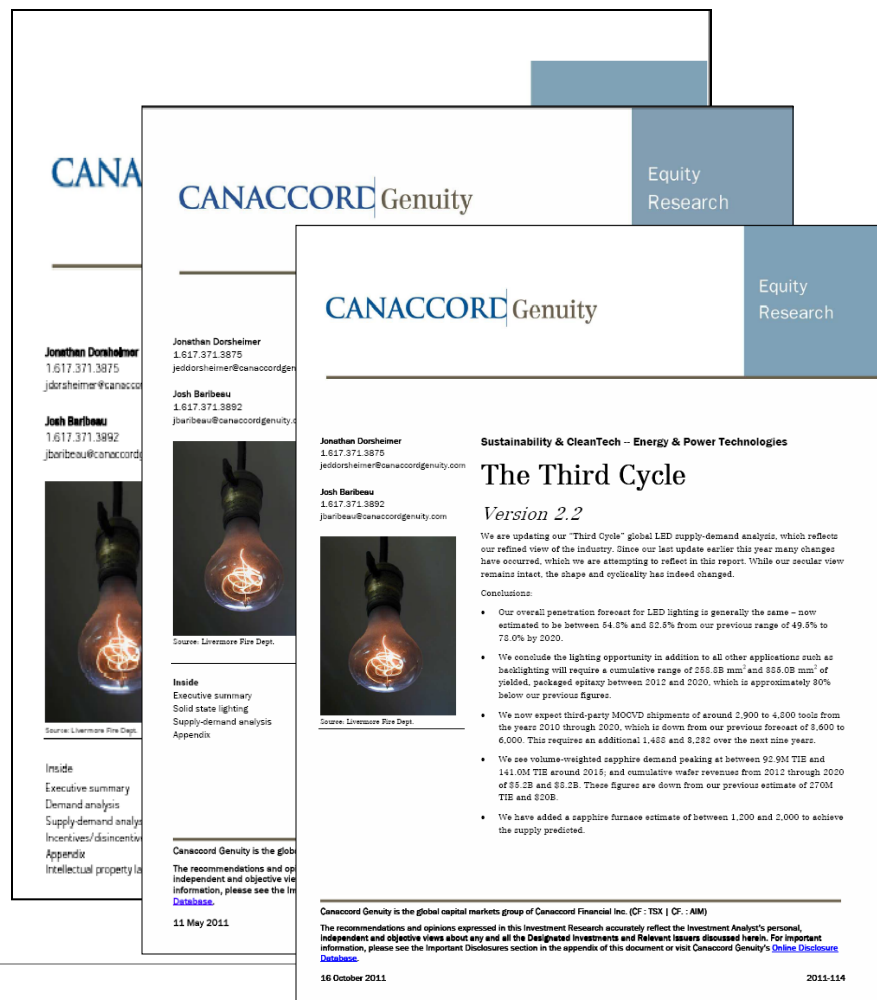
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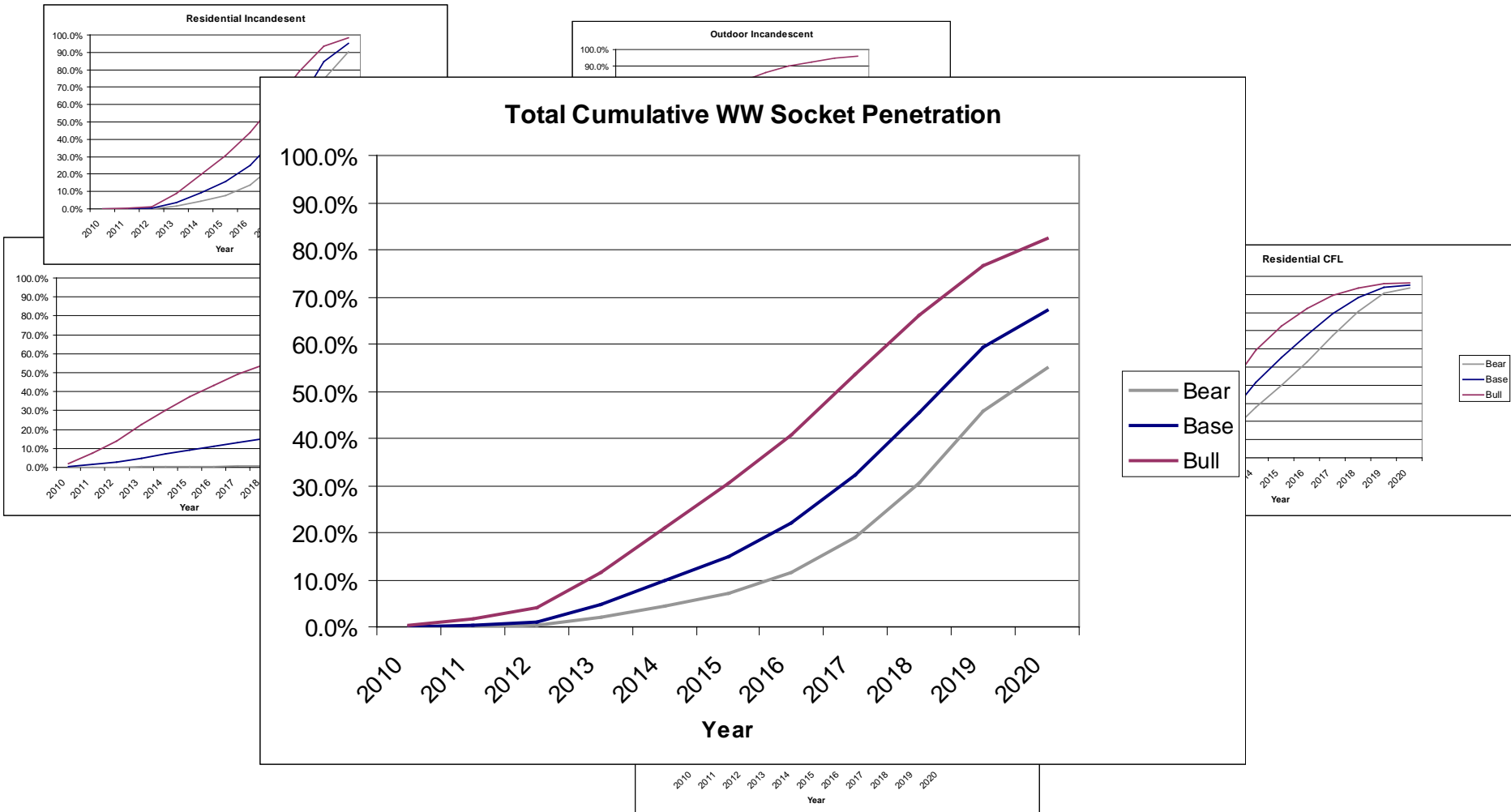
# The Third Cycle

Complete proprietary bottoms-up assessment of overall lighting industry & True CoO model for LED penetration over hundreds of scenarios to 2020



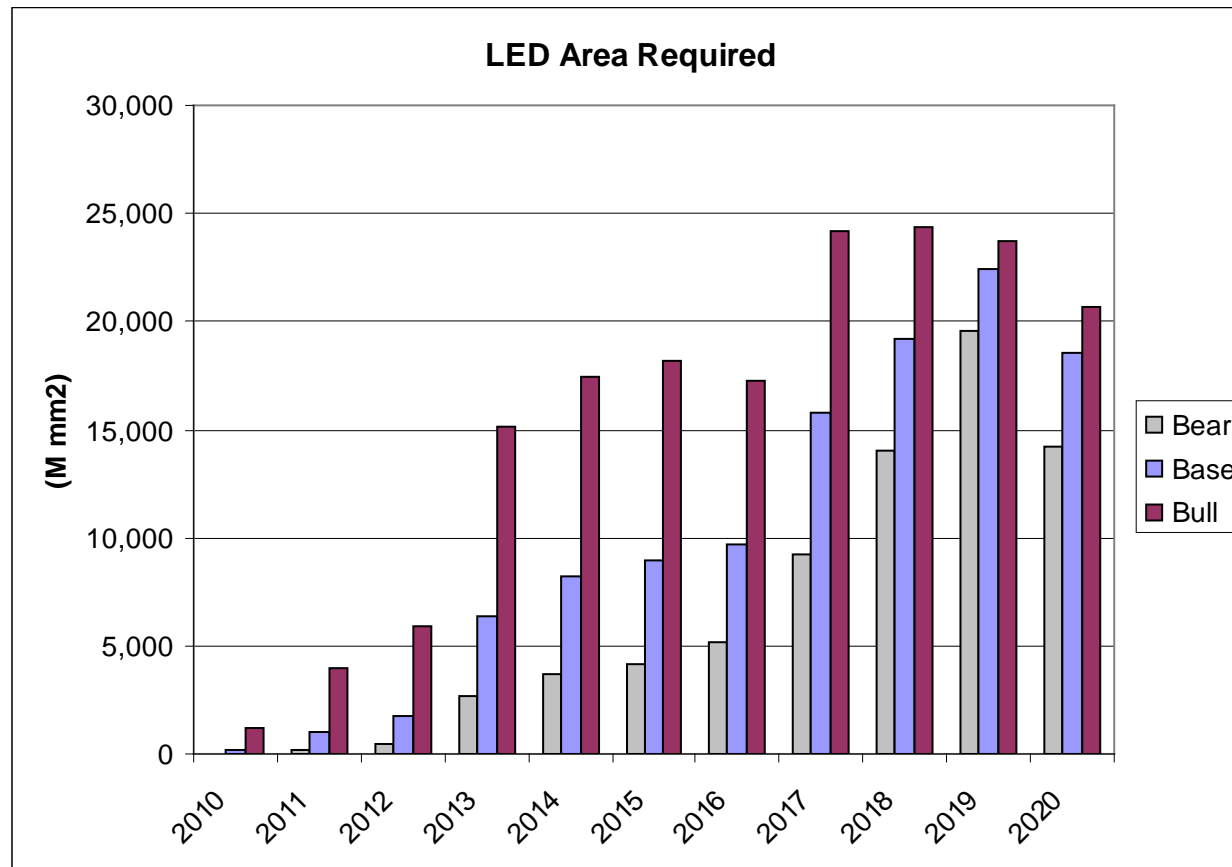
# Adoption Curves – Cumulative

- 54.8% to 82.5% by 2020



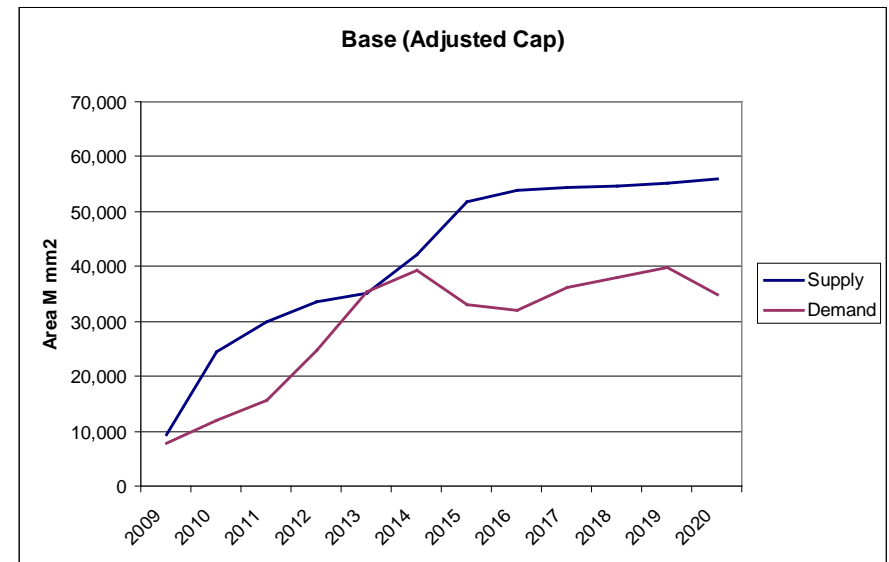
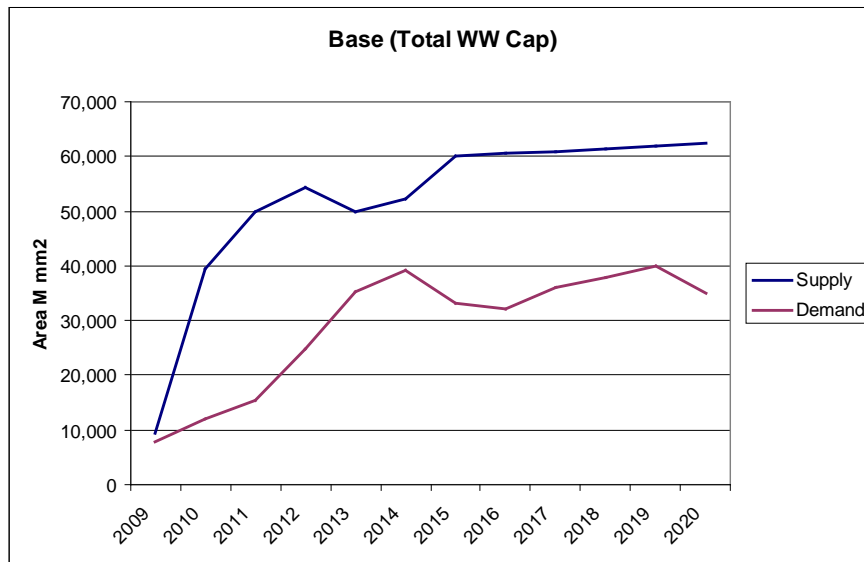
# Adoption Curves – Cumulative

- 73.0B and 167.0B mm<sup>2</sup> of yielded, packaged epi for lighting between 2012 and 2020

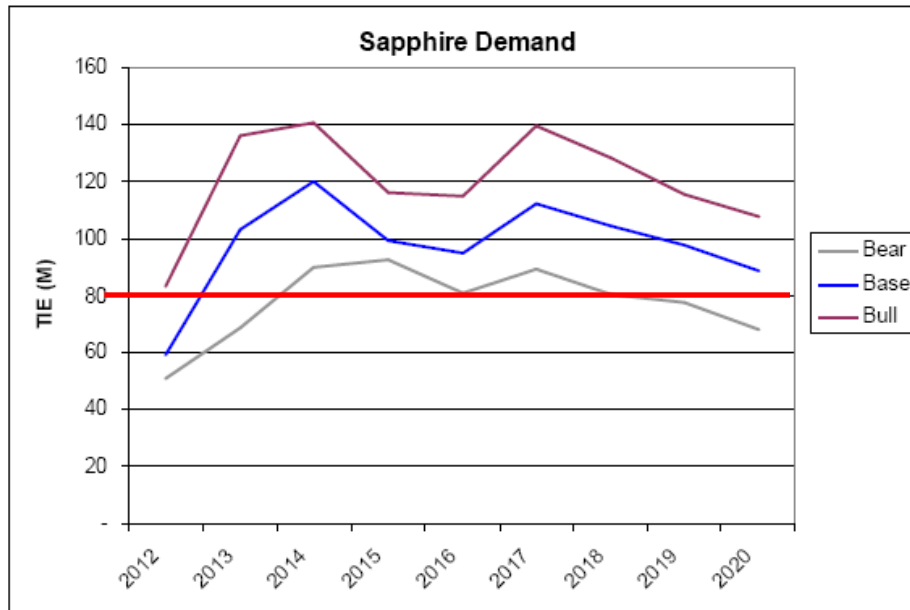


# Projected LED supply-demand

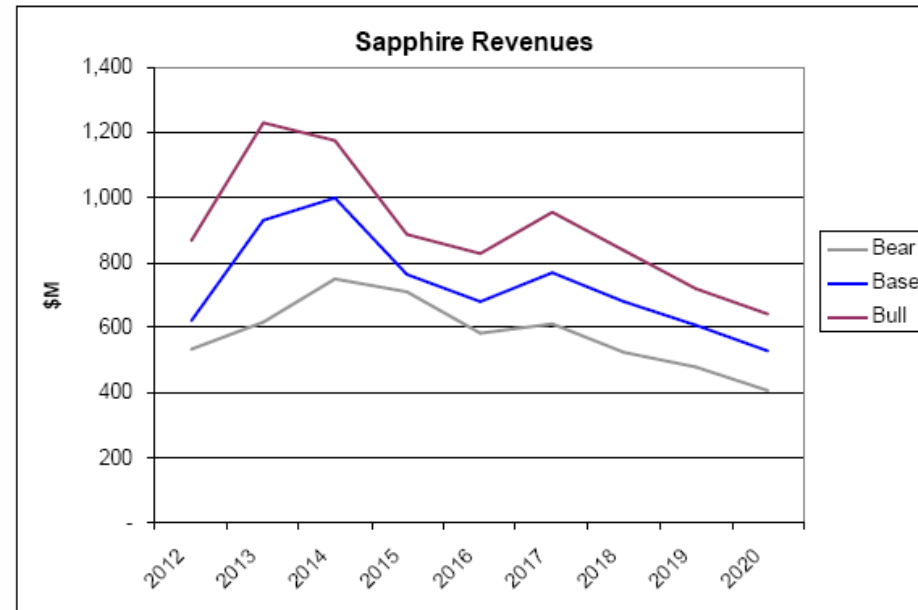
- 200% growth in supply and 90% growth in demand from 2009-2011
  - Oversupply could commoditize the market, spur new wave of LED adoption
- Flattening of LED demand
  - Growing OLED penetration in trad. LED markets, gradual lighting adoption, improvements in LED efficacy



# Sapphire Supply-Demand



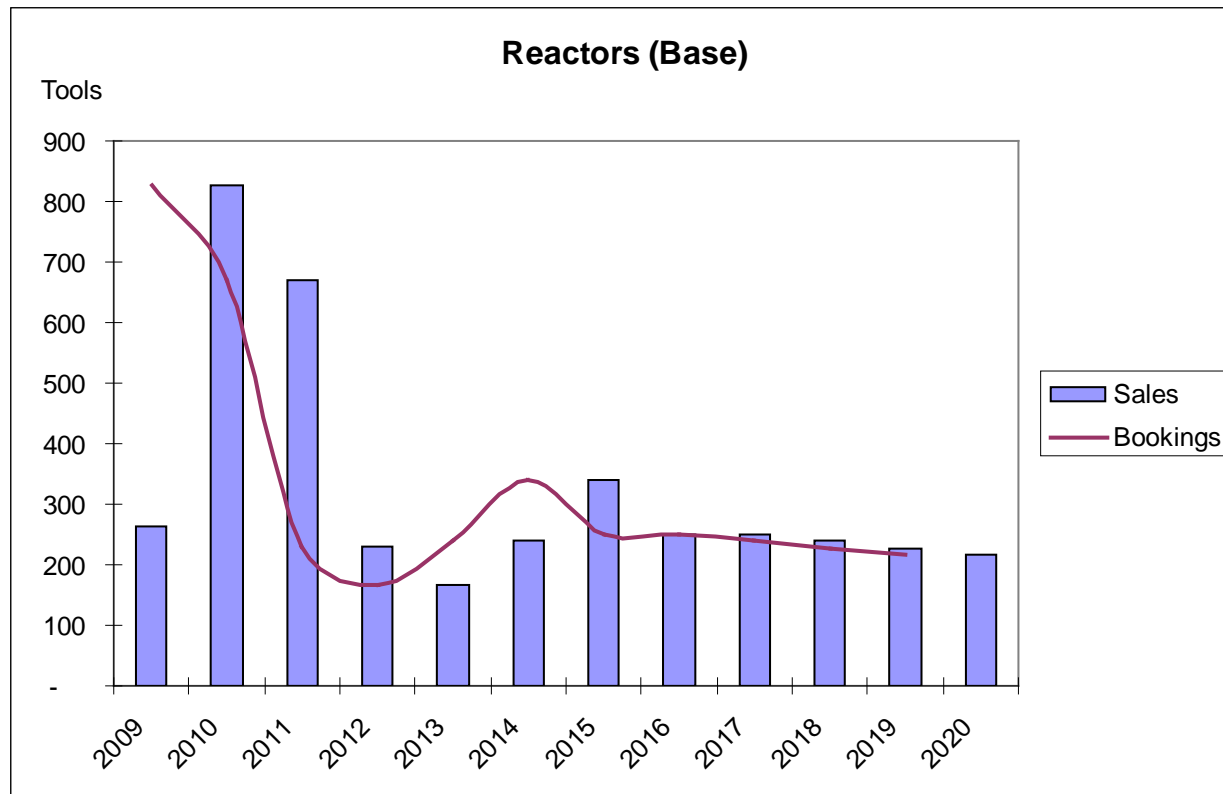
— Supply at 1/1/2012 (80M TIE)



MOCVD – where is the semi cycle?

# MOCVD

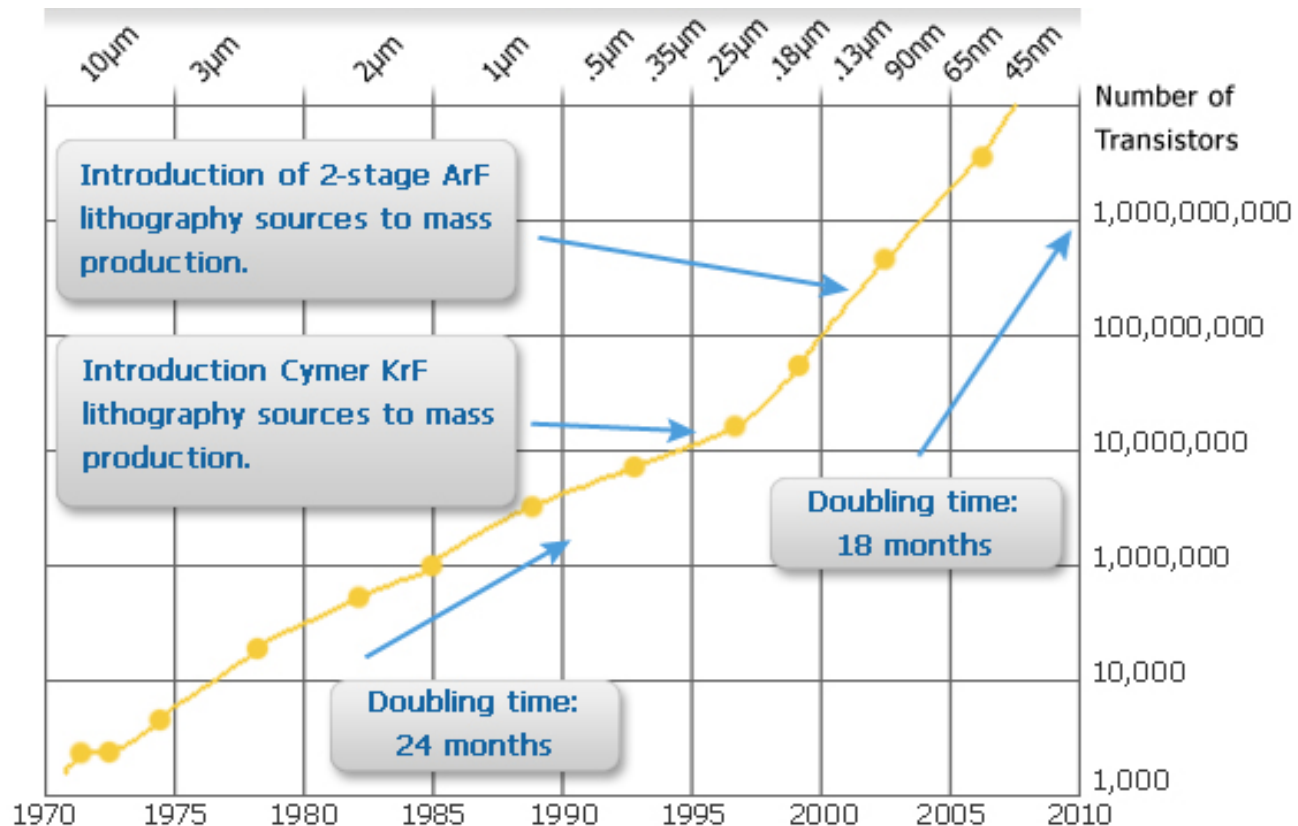
- 2,900 to 4,800 tools projected from 2010-2020
  - ~300 average per year
  - 1600 from 2009-2011, only 1500-3200 remain





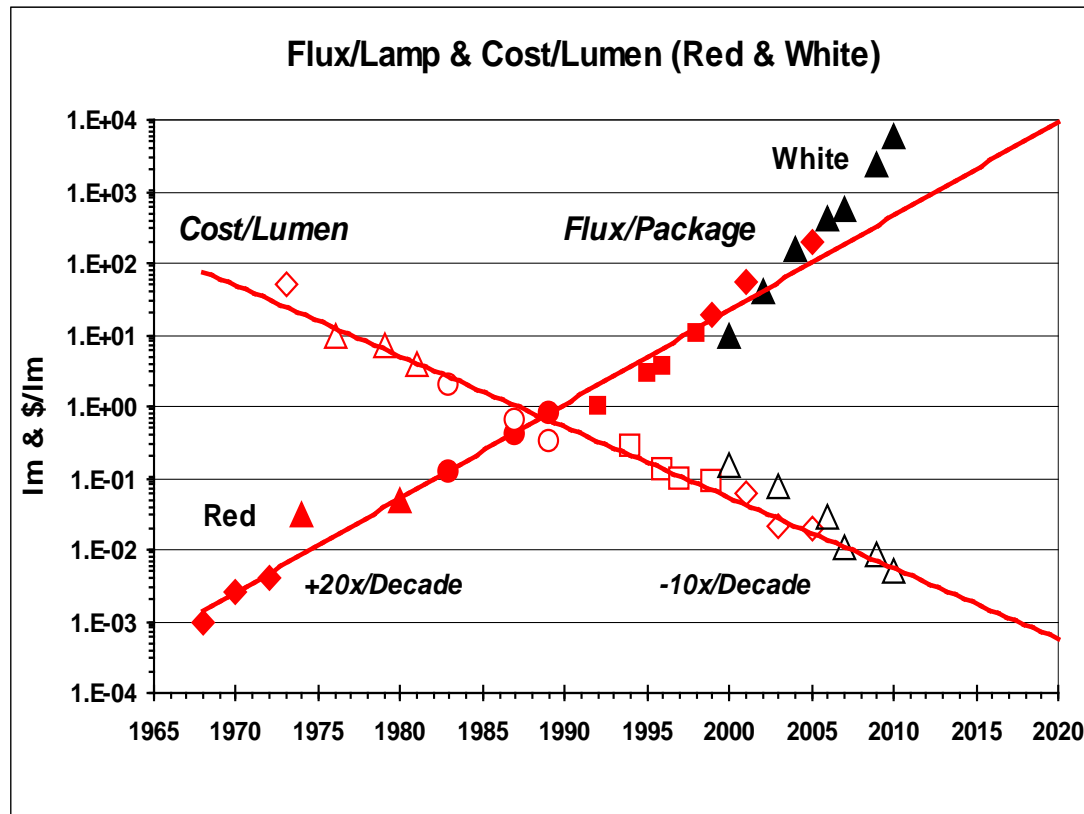
# Gordon Moore

- Moore's law driven by fundamental geometry changes
- Geometry changes required increasingly complex equipment
  - Created perpetual equipment replacement cycles



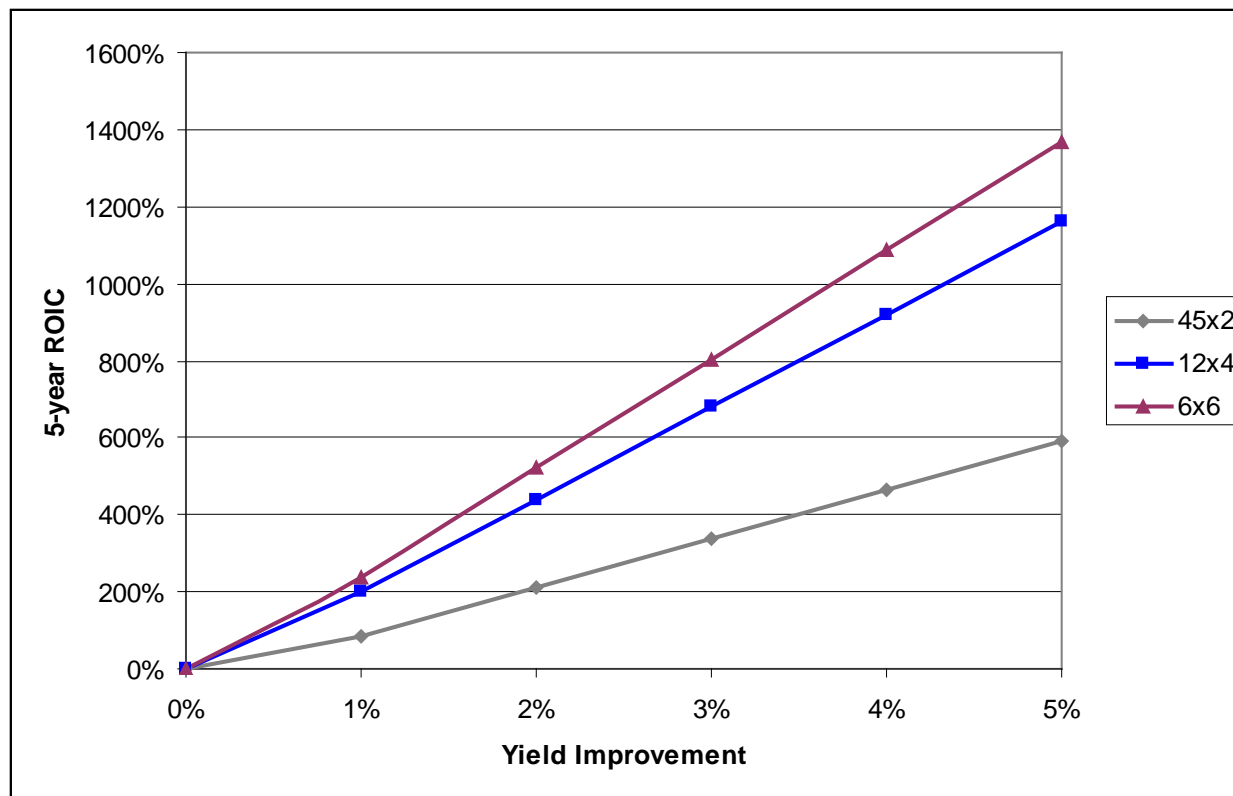
# Roland Haitz

- Haitz' law analogous from a cost/performance perspective
- BUT not dependent on physical geometry
  - Does not require equipment upgrade cycles



# Replacement cycle

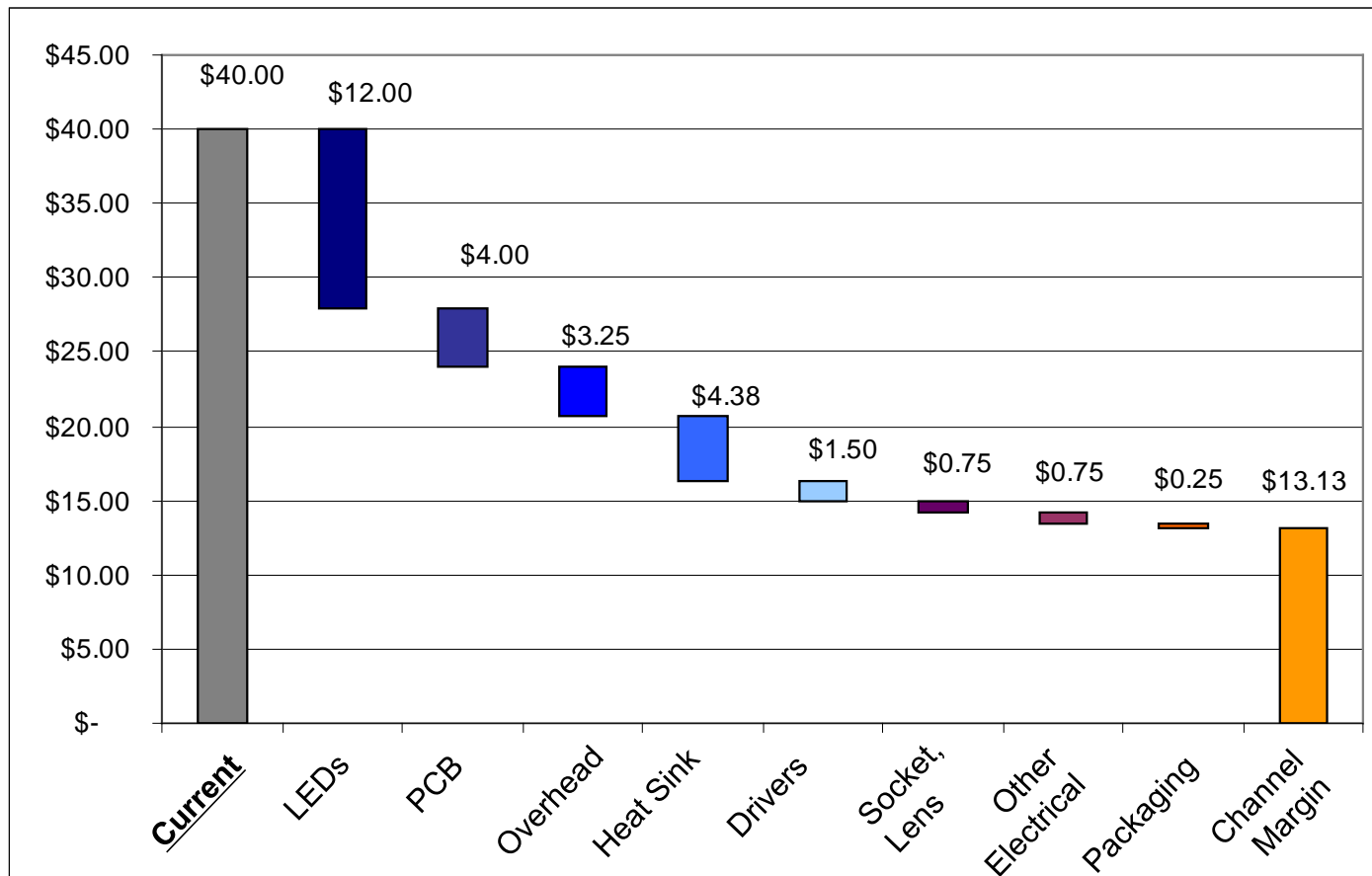
- It is possible to generate high NPV by purchasing new equipment
- ROIC much higher by modifying process on existing equipment
  - Even modest increases in yield give tremendous returns



What does this all mean to you?

# \$40 to \$4 how does this happen?

## 60W LED Lamp Bill of Materials



## Yield: Epi (MOCVD), Chip, Package

- Yield stacking = 10% - 65% combined!
  - Epi: <30% - 90%
  - Chip: 50 – 80%
  - Package: 65% - 90%
- Memory/Logic market >95%
- Much room for improvement

# System Efficiency

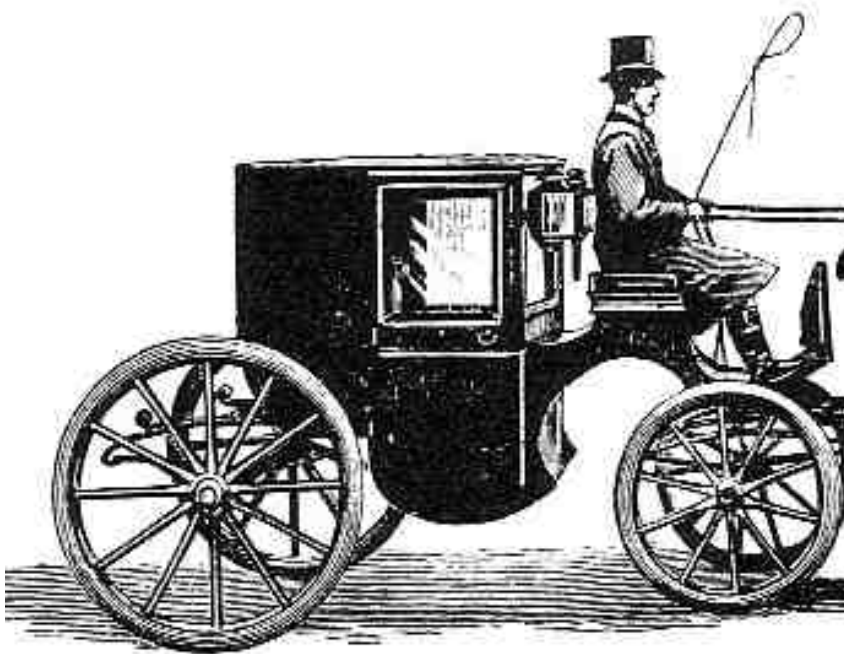
- 25% - 30% losses currently
  - Electrical
  - Thermal
  - Optical



# Beyond the myopic solutions



# Evolution



LOOK FAMILIAR?

# Evolution



# Expanding the TAM

- White LED backlighting enabled color screens
- Color screens enabled the smart phone revolution
  - From nearly ZERO in 2000 to 471M units in 2011\*



\* Canaccord Genuity Global Handset Forecasts

## From efficiency...



2007: Lexus LS 600h first car to use LED daytime running lights  
=1mpg savings!

## ...to Branding



Today we recognize Audi in our rear view mirrors by the headlights

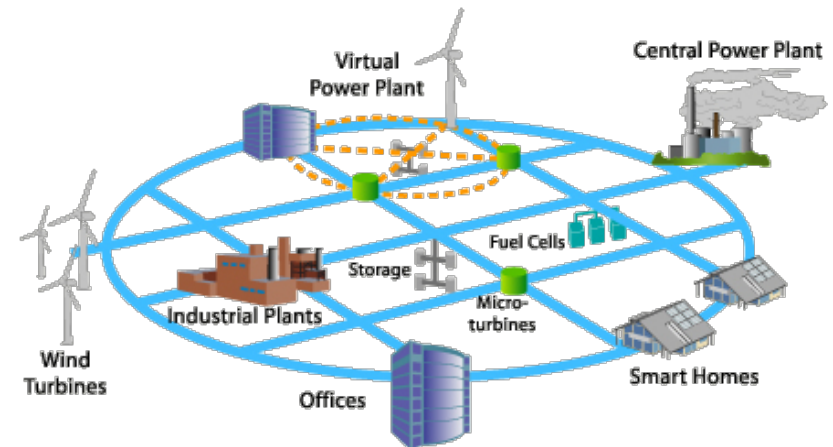
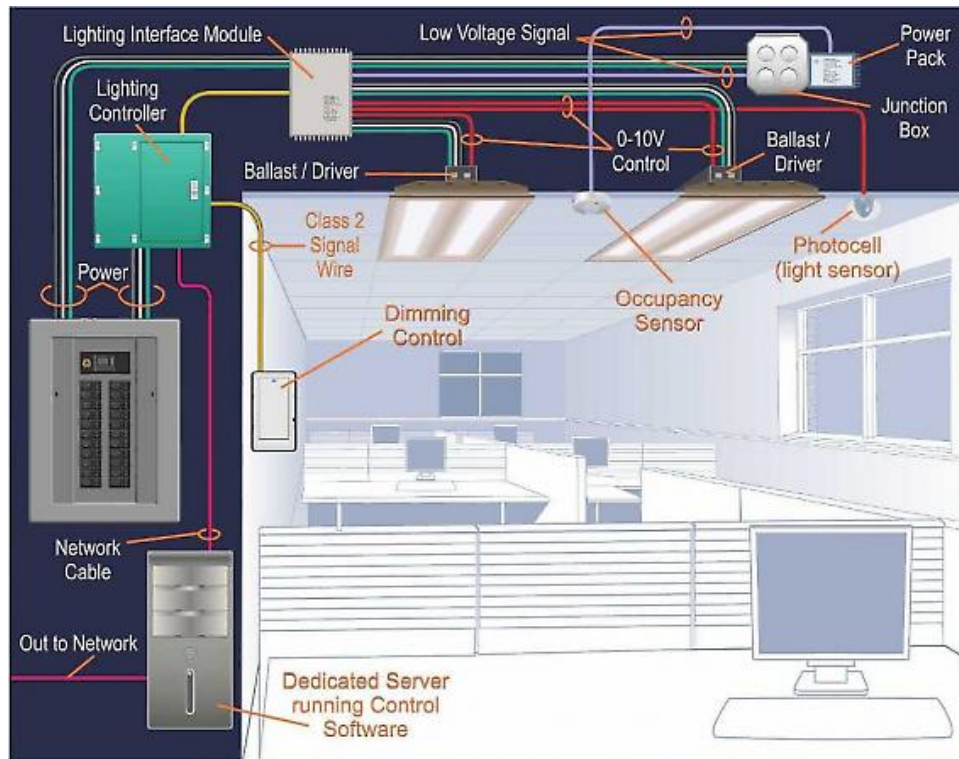
# From efficiency...



## Today it's all about instant energy savings



## ...to information



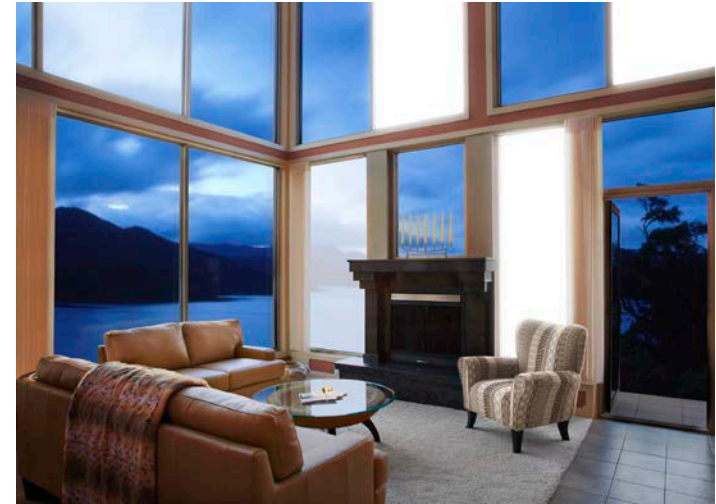
In the future most lighting could be networked, leading to greater insight into our energy consumption patterns and optimized electricity generation/distribution

# OLEDs in lighting



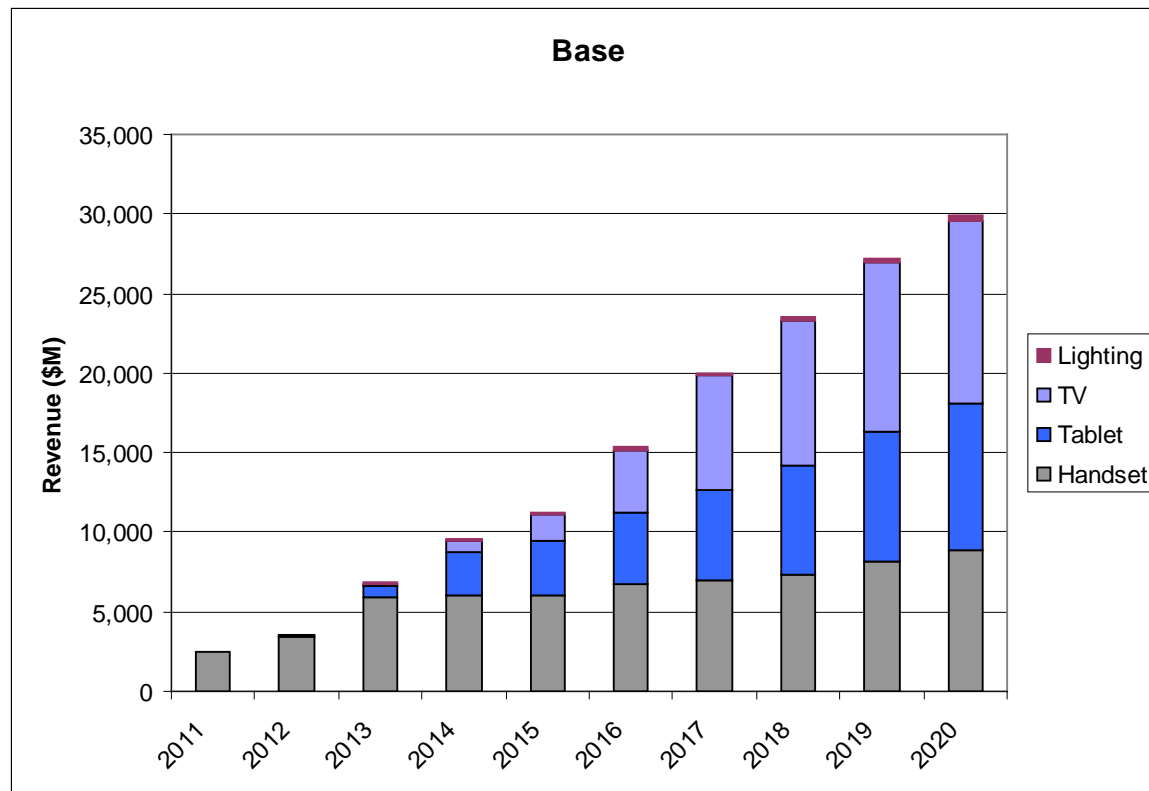
# OLED

- Pros
  - Simpler design
  - More flexible form factor
- Cons
  - Manufacturing/scale challenges
  - Lifetime
  - Efficiency hurdles vs. inorganic LED



# OLED

- Promising technology but likely limited to niche lighting
- Majority of OLED still driven by display
- Lighting: \$200M - \$300M annual opportunity



# Conclusions

- LED will be the “hidden gem” of the Cleantech/Sustainability movement
- Upstream investments have been made
  - Allows for costs to come down exponentially
- Government incentives will help but not required
  - Standards might be better
- LEDs will begin as an energy efficiency story
  - Blubs to fixtures
  - As in all other applications of LEDs transformation will occur beyond energy savings
- Downstream innovation and standards are key

Thank you!

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	970	100.0%	

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